TECHNICAL MEMORANDUMS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.



No. 283

# MOORING AIRSHIPS

By G. A. Crocco

From "Note di Tecnica Aeronavale," 1923.



October, 1924.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

TECHNICAL MEMORANDUM NO. 283.

# MOORING AIRSHIPS.*

By G. A. Crocco.

The purpose of this paper is to summarize the present status of the problem. The mooring of seaships, accomplished by anchoring the bow and leaving the ship free to swing with the current, offers no practical difficulty, both because the ship has freedom of motion in only one plane and because the velocity of sea currents is relatively small. It is only necessary therefore for the ship to drop two anchors, in order to establish a sufficiently fixed point about which it can swing, so as to keep the bow toward the current.

The same can not be said of an airship, both on account of the greater degree of freedom possessed by it in space and on account of the greater velocity of the air currents to which it may be subjected and also on account of their varying intensity and direction.

The most complicated case is that of mooring by means of a single cable, which we will reserve for special attention in the future, on account of its importance as the transition stage between free navigation and fixed mooring. It is the case of the captive balloon, which can be rendered practically stable by the adoption of suitable devices.

* From "Note di Tecnica Aeronavale," 1923, pp. 18-24. This paper was read before the "R. Accademia dei Lincei," (Rome, Italy), May 9, 1923.

The purpose of these devices is to maintain a permanent inclination of the longitudinal axis capable of generating a lifting force like that of a kite. This force, in conjunction with the inherent ascensional force of the balloon, maintains a tension on the cable and counteracts the downward tendency due to the force of the wind.

In the case of an airship, it is likewise necessary to keep the cable under considerable tension, partly by releasing ballast, partly by the longitudinal transfer of water, and partly by the dynamic action of the elevators.

Under certain conditions it is thus possible to obtain a position of stable equilibrium, about which an airship can oscillate in all directions, while the pilot, by means of the control surfaces, can reduce the oscillations and change, if necessary, the position of equilibrium.

The operation is less complicated, if the lateral motions are impeded by means of two diverging cables, the same as in anchoring a ship. Thus a triangle is formed, with the vertex at the bow of the airship and the base, on the ground, becomes the axis of oscillation. If, in such a case, the airship is sufficiently stabilized with reference to the vertex of the triangle, the oscillations in the horizontal plane become practically negligible and the motions are limited to rotations about the base of the triangle, caused by gusts of wind and by the resulting oscillations of the airship's axis about the vertex of the triangle.

Assuming that the tension of the cable is caused only by the dynamic ascensional force, varying as the square of the wind's velocity and with the direction of the airship's axis; that the downward force of the wind is also of quadratic form and almost independent of the direction of the axis; and, lastly, that the static straightening couple is exactly offset by the shifting of the water ballast, a position of equilibrium of the plane of the triangle is obtained, determined by the orientation and independent of the velocity of the wind and therefore of gusts.

The oscillations about this position depend principally on variations in the direction of the wind, their amplitude and duration and on the particular characteristics of the airship with respect to the length of the cable.

The adoption of a third cable forming, with the other two, a funicular pyramid, somewhat lessens the oscillations of the apex, within the limits of tension of the cables and their angular aperture. This method gives considerable stability, provided the airship is stable with respect to the point of the bow where the apex of the pyramid is located.*

This was the precursor of the mooring mast, in which the apex of the funicular pyramid is replaced by the top of a rigid mast sunk

* A similar method of mooring was invented by us in 1908 and employed in maneuvering our military airship "1 bis" at Vigna di Valle, as recorded in the log book.

into the ground and held by guy-ropes.*

The mooring mast, now in vogue in England and America, eliminates the necessity of the lifting force for maintaining the tautness of the funicular systems and creates a fixed center of rotation. This method, however, like the funicular systems, requires the airship to be stabilized with respect to this fixed center. Hence the problem of such stabilization assumes a predominant importance in the determination of the stabilizing surfaces.

The necessity for such stabilization is due to the existence of a disturbing couple of the elongated hull, as explained by Renard ("Comptes rendus," Nov. 23, 1903), in connection with the oscillations of pitching. Renard deduces the values of the quantity which he calls "critical velocity" and "impennagio stretto."

We supplemented Renard's theory "G. A. Crocco, "Stabilita dei dirigibili," Rendiconti Accademia Lincei," Nov. 20, 1904), by introducing, always for an airship in free motion, the vertical motion of the center of gravity and the couples of shock absorption. We thus obtained a value of the "impennagio stretto," in navigation, smaller than Renard's.

In developing the theory of Renard and corroborating it by experiments (G. A. Crocco, "Dinamica dei dirigibili," Bolletino Societe Italiana, Nos. 4 and 5, 1907), we emphasized the question of the stability of captive balloons. This question, especially

* This type of mooring was invented by us in 1916 and constructed at the "Istituto Sperimentale Aeronautico." It was not employed, however, in any of the regular airports.

after the accident to the "Patrie," guided us in the practical determinations of the control surfaces and led us to adopt automatic multiplane elevators (G. A. Crocco, "Introduzione alla teoria dei timoni automatici," a paper read at Cagnola, in 1912, before the "Istituto Lombardo di Scienze e Lettere").

The high speeds since attained by airships have led to a refinement in their lines and the use of monoplane stabilizing surfaces, disposed in the form of a cross at the stern, together with much elongated control surfaces in continuation of the keel. This gives larger but more penetrating stabilizing surfaces. We will, however, report the results of the latest experiments with a model of the Zeppelin L 49, performed in the aerodynamic department of our "Istituto Sperimentale Aeronautico," in 1922.

Representing the angle of orientation with respect to the wind by $\alpha$, the velocity of the wind by $v$, and the volume of the hull by $V$, the disturbing couple with respect to the center of gravity is, for small angles, $C_0 = 0.077\ V\ \alpha\ v^2$, while the couple with reference to the center of mooring, at the bow, has the value $C = 0.035\ V\ \alpha\ v^2$, which is about half the above.

If, on the other hand, $\sigma$ and $\lambda$ respectively, represent the area and mean distance of the control surfaces from the bow, this furnishes a straightening couple $k\ \sigma\ \lambda\ \alpha\ v^2$ for small angles and hence $k\ \sigma\ \lambda$ either equals or exceeds $0.035\ V$.

On putting, for homogeneity, the volume $V$ in the type represented by $V = 0.78\ S\ \lambda$, in which $S$ is the largest cross-section

of the airship, we obtain the expression of sufficiency $k\,\sigma = 0.0273$ in which the coefficient k must be found experimentally for keels of elongated shape with the control surfaces located in the wake of the hull.

This coefficient is about 0.8. (Renard obtained 0.174 and we assumed 0.16 for square surfaces far from the wake.) Consequently, we obtained $\sigma = 0.34S$ and can state definitely, as the general law concerning the order of magnitude of the control surfaces, that the keel surface necessary to stabilize a hull of the type mentioned is about one-third of the master section.

Thus, by adopting control surfaces somewhat larger than the ones mentioned, it is possible to stabilize the orientation of airships moored to masts. There are some difficulties, however, as regards the horizontal equilibrium.

First of all, the mast must be tall, in order to remove the airship from the influence of the ground. Otherwise, every gust would exert a lifting force upon it. A high mast has the disadvantage of difficult accessibility.

In the second place, it is difficult to keep the axis horizontal, on account of the variations in the static lifting force due to shifting the load and replenishing and to variations in solar radiation. The lifting and depressing forces of the wind keep the airship in continual oscillation, both vertical and horizontal.

Hence we prefer the type of fixed mooring invented by us in 1914 (patent No. 138061 of Nov. 19, 1912, presented to the Italian

Government and since allowed to expire). This consists in attaching the airship (throughout its entire length, or a sufficient central portion) to a platform capable of rotating about a vertical pivot on a circular track. This platform is kept in the direction of the wind by mechanical means.

The fundamental principle of such a mooring is to keep the airship motionless on the platform and to cause the weight and strength of the platform to assist in withstanding the force of the wind. Thus all the chief difficulties of mooring are overcome. Since the airship is fastened throughout the greater portion of its length, the air waves due to the unevenness of the ground do not cause variations of ascensional force, while variations in the intensity and direction of the wind do not cause dynamic oscillations and stresses, but simply internal stresses in the connections within foreseeable limits. It suffices, therefore, for the whole to be statically capable of withstanding these forces, taking into account the fact that they generate not only vertical, but also longitudinal and lateral moments.

The wind gusts and the variations in direction and velocity are felt along the entire body of the airship from stem to stern. In the second place, the dissymmetry, due to the presence of the ground and the platform, creates vertical waves, especially toward the bow. Lastly, the mechanical orientation in a mean direction, between the momentary directions, exposes the hull, within certain limits, to oblique winds.

After eliminating these effects, we will then determine the weight of the platform, including possible ballast and connections, running easily on tracks, with respect especially, to the lateral forces. At the same time, we will calculate the bending moments to be withstood by the platform. Of course the weight must correspond to the number of supports, i.e., the central pivot and the end wheels, so as to be easily operated. (A good solution of this problem was found by the Savigliano Company, of Turin, in the design, before the war, of a platform intended for the military airdrome at Ciampino).

The above-mentioned calculations will moreover render it possible to determine the nature of the connections between the airship and the platform, which is of prime importance. These connections, in their simplest form, are cable moorimgs of suitable points along the airship. These cables are ordinarily kept taut by the lifting force of the hull, generated, for example, in a commercial airship, by the debarkation of passengers, as also by replenishing the gas, or by the release of the water ballast obtained by condensing the water in the exhaust gases. Where such a lifting force is not available, the cables can be put under tension by supporting the weight of the cars on the platform. Lastly, if the latter are not suspended by cables, the airship can be supported on movable horses. Hence, it is always possible to obtain a firm connection.

The above-described mooring is safe and practical, because it not only makes it possible to withstand exceptional stresses at the

bow and, within certain limits, from the side, but also because it renders the airship easily accessible. All operations, such as loading and unloading, or replenishing with gas or ballast, thus become possible in the open; as likewise the principal repairs, such as patching, varnishing, changing gas bags and replacing engines or cars. This method of mooring requires less space on the ground and also renders landing less difficult and dangerous.

Translation by Dwight M. Miner,
National Advisory Committee
for Aeronautics.